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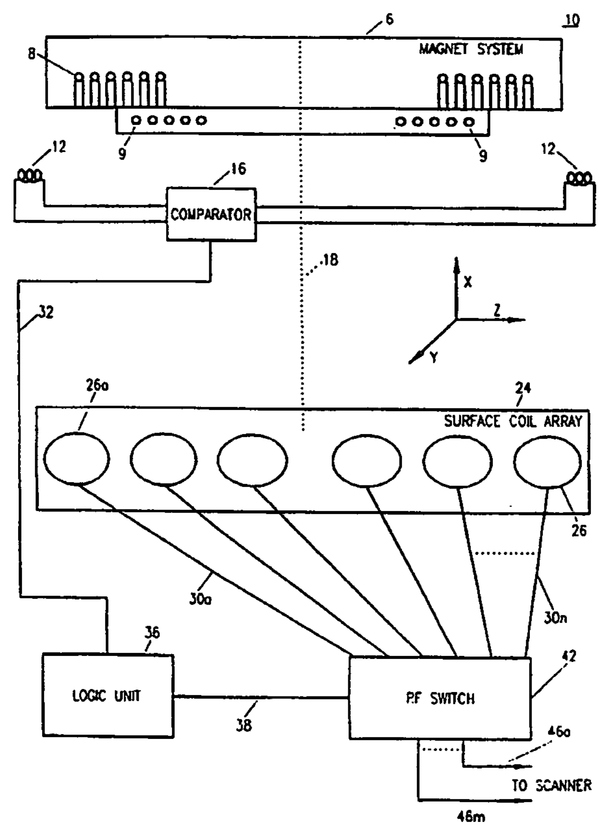
(54) Title: AUTOMATIC COIL ELEMENT SELECTION IN LARGE MRI COIL ARRAYS

(57) Abstract

A method of and system for selectively enabling at least one of a plurality of receive coils (26 a.n) of a coil array (24) for use with a magnetic resonance imaging system having a magnetic field, viz. a static magnetic field, a gradient magnetic field and a transmit excitation radio frequency magnetic field and a plurality of receive coils movable with respect to the magnetic field includes sensing the magnetic field by means of at least one sensor (12) having a known position. At least one of the plurality of receive coils is selected in accordance with the sensing, and is enable to form a magnetic resonance image. The sensor may include a plurality of sensor coils (12) disposed at differing locations within the magnetic field to sense the differing field amplitudes and/or phases thereof. The differing field intensities cause differing voltage amplitudes and/or phases to be induced on the sensor coils. The differing voltage amplitudes and/or phases are compared to determine the relative positions of the magnetic isocenter of the system and the receive coils to be enabled.



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AUTOMATIC COIL ELEMENT SELECTION IN LARGE MRI COIL ARRAYS

BACKGROUND OF THE INVENTION

The present invention relates to magnetic resonance imaging ("MRI") and, more particularly, to a method and an apparatus for selectively enabling coils in an MRI host device.

Initially, MRI systems used whole body coils to image subjects, such as human patients. The whole body receive coils of these systems had the advantage that sensitivity was, to a first approximation, substantially constant over the entire region being imaged. While this uniformity in sensitivity was not strictly characteristic of such whole body receive coils, the sensitivity was substantially constant to a degree that most reconstruction techniques assumed a constant coil sensitivity. Due to their large volume, however, the whole body receive coils suffer from a relative insensitivity to individual spins.

For certain applications, a surface coil is preferable to a whole body receive coil in MRI systems. For an example of a surface receiving coil, see U.S. Patent No. 4,793,356 to Misic et al. Surface coils can be made much smaller in geometry than whole body receive coils, and for medical diagnostic use they can be applied near, on, or inside the body of a patient. This is especially important where attention is directed to imaging a small region within the patient, rather than an entire anatomical cross section. The use of a surface coil in MRI systems also reduces the noise contribution from electrical losses in the body in comparison to a corresponding whole body receive coil, while maximizing the desired signal. MRI systems thus typically use small surface coils for localized high resolution imaging.

A disadvantage of surface coils, however, is their limited field of view. A single surface coil can only effectively image a region of a subject having lateral dimensions

comparable to the surface coil diameter. Therefore, surface coils necessarily restrict the field of view, and inevitably lead to a tradeoff between resolution and field of view. Generally, large surface coils generate more noise due to their exposure to greater patient sample losses and therefore have a larger noise component relative to the signal, while smaller coils have lower noise but in turn restrict the field of view to a smaller region.

One technique for extending the field-of-view limitation of a surface coil is described in U.S. Patent No. 4,825,162, entitled "Nuclear Magnetic Resonance (NMR) Imaging with Multiple Surface Coils," issued to Roemer et al. Roemer et al. describes a set of surface coils arrayed with overlapping fields of view. Each of the surface coils is positioned to have substantially no interaction with any adjacent surface coils. A different response signal is received at each different surface coil from an associated portion of the sample that was enclosed within an imaging volume defined by the array. Each different response signal is used to construct a different one of a like plurality of different images of the sample. The different images are then combined to produce a single composite image of the sample. Roemer et al. describes a four coil array for imaging a human spine.

While an increased number of surface coils can be used in this manner to increase the field of view of MRI systems, MRI system scanners typically have a limited number of simultaneous data acquisition channels or receivers, and a limited number of selectable inputs. The number of selectable inputs is typically equal to the number of receivers. In some cases the number of selectable inputs is double the number of receivers, each receiver being capable of selectively receiving from either of two inputs. The number of data acquisition channels and separate inputs is therefore a design limitation on the number of phased array surface coils that can be used in an MRI system. A disadvantage of conventional phased array surface coils, therefore, is that the surface coil array can include

only the number of surface coils that can be directly connected to the phased array inputs of the system scanner. The number of simultaneous data acquisition channels, or receivers, can be a further restriction on the utility of surface coil arrays.

To overcome the limitations of MRI system scanners imposed by the limited number of data acquisition channels or receivers, and the limited number of inputs, MRI technicians have resorted to physically moving the surface coils or manually switching selected groups of coils after successive scans to obtain MRI images. As can be appreciated, these techniques require excessive scan room intervention by personnel operating the MRI systems. That is, after each scan a technician must enter the scan room to physically reposition the coils, or manipulate a local selector switch to reconfigure the active coils of a large array to those needed to cover the desired patient anatomy. These scan room intervention techniques increase examination time and the likelihood of a patient rejecting the procedure.

SUMMARY OF THE INVENTION

The present invention provides automatic selection of phased array coil elements appropriate for an anatomical region being scanned, without scan room intervention by MRI personnel. In one aspect of the present invention, coil elements of the array may be automatically selected to image anatomical regions of a patient according to the locations of the coil elements relative to the isocenter of the MRI system. In another aspect, coil elements appropriate for an anatomical region to be scanned may be selected by moving the target anatomy of the patient to the magnetic isocenter of the MRI system.

According to a first preferred embodiment of the present invention, a method for magnetic resonance imaging of a subject in an imaging system having a magnetic field includes: providing a plurality of receive coils movable with respect to the magnetic field;

providing a sensor having a known position with respect to the subject; and sensing the magnetic field with the sensor. At least one receive coil of the plurality of receive coils is selected in accordance with the sensing by the sensor. In response, the selected receive coil is enabled to form an image of the anatomical region of the subject.

In a preferred embodiment, the position of the phased array coil relative to (1) the isocenter of the system main magnet that creates the static [B0] magnetic field, and (2) the coils creating the transmit RF and/or gradient time varying [B1] magnetic fields is determined. A switch may be used to selectively enable the appropriate coil elements and to connect them to the phased array coil inputs of the host MRI system. The selected receive coil elements are used to form an image of the region of anatomy desired for a particular scan operation.

According to a second preferred embodiment of the present invention, a magnetic resonance system having a magnetic field includes a plurality of receive coils movable with respect to the magnetic field for imaging a subject, a sensor having a known position with respect to the subject for sensing the magnetic field, and a switching device for selecting one or more of the receive coils in accordance with the sensing of the magnetic field by the sensor.

According to another preferred embodiment of the present invention, a magnetic resonance system for determining the position of a subject within a magnetic field includes a sensor device having two or more spaced sensors movable with respect to the magnetic field. The sensors sense the amplitudes of the magnetic field at different locations within the magnetic resonance system and determine the position of the subject in accordance with the sensed amplitudes.

By providing automatic coil selection. the present invention eliminates the need for scan room intervention by MRI technicians to physically reposition the surface coils or to manually switch selected groups of coils after successive scans to image desired patient anatomical regions. Thus, the present invention can decrease both examination time and the likelihood of a patient rejecting the procedure.

The present invention, along with further aspects and attendant advantages, will best be understood by reference to the following detailed description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a schematic representation of the magnetic resonance imaging system of the present invention.

Figs. 2A and 2B show graphical representations of magnetic fields provided within the magnetic resonance imaging system of Fig. 1.

Fig. 3 shows a schematic representation of a further alternate embodiment of the magnetic resonance imaging system of Fig. 1.

Fig. 4 shows a schematic representation of a further embodiment of the magnetic resonance imaging system of Fig. 1.

DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EMBODIMENTS OF THE INVENTION

Referring now to Fig. 1, there is shown a magnetic resonance imaging system 10 in accordance with a preferred embodiment of the present invention. Magnetic resonance imaging system 10 includes a magnet system 6 for providing a static magnetic field and applying the static magnetic field to an imaging subject, for example a human being, in order

to form an image of the imaging subject. Magnet system 6 includes coils 8 for providing the static magnetic field, B0, of resonance imaging system 10, gradient field coils 9 for producing the audio frequency gradient field, B1, and a body coil for producing the radio frequency gradient field, RF B1.

Magnetic resonance imaging system 10 also includes surface coil array 24 for receiving the magnetic field energy produced by the subject patient in response to the imaging procedure within magnet system 6 and for providing electrical signals according to the received NMR signal to form the image of the subject. System magnetic isocenter 18 of the magnetic field provided by magnet system 6 passes through the horizontal center of magnet system 6. Isocenter 18 is horizontally translatable with respect to surface coil array 24 and the subject being imaged. Surface coil array 24 and the subject are also horizontally translatable with respect to the isocenter 18.

N surface coils 26a-n are included within surface coil array 24. The number N of surface coils 26a-n within surface coil array 24 can be any value, for example, N can be between two and twenty. Furthermore, surface coils 26a-n can be any type of receive coil. Each of the N surface coils 26a-n of surface coil array 24 is provided with a corresponding coil signal output line 30a-n. Each coil signal output line 30a-n can transmit an electrical signal representative of an image of a portion of the subject from its corresponding surface coil 26a-n during imaging of the subject.

According to the method of the preferred embodiment, surface coils 26a-n are selectively enabled within nuclear magnetic resonance imaging system 10 in order to scan selected regions of interest of the imaging subject with high resolution. In order to perform this method, M output signal lines 30a-n corresponding to selected surface coils 26a-n within surface coil array 24 are selectively coupled to M inputs 46a-m of imaging system 10, for

forming different images, wherein N > M. While output signal lines 30a-n of the corresponding selected surface coils 26a-n are coupled to inputs 46a-m in this manner, the output signals of the remaining N-M unselected surface coils 26a-n are not coupled to any inputs and the N-M unselected surface coils 26a-n are thus electrically disabled. Inputs 46a-m can be preamplifier inputs to an MRI system scanner.

The coupling of the M corresponding coil output signal lines 30a-n of the selected surface coils 26a-n to the M preamplifier inputs 46a-m can be performed by RF switch 42. Which M of the N surface coils 26a-n are coupled to preamplifier lines 46a-m by RF switch 42 is determined by control signals on switch control line 38 under the control of logic unit 36. The control signals applied to switch control line 38 by logic unit 36 are determined according to sensing signals applied to logic unit 36 by way of sense line 32.

The sensing signals of sense line 32 are representative of the position of the surface coil array 24 relative to the position of system magnetic isocenter 18. The relative position of magnetic isocenter 18 and coil array 24 can be determined by surface coil position sensor 14 in a number of ways. One preferred method of making this position determination is by sensing the gradient coil audio frequency magnetic pulses provided by gradient field coil 9. For example, the Z-axis gradient pulses can be sensed to make the position determination.

In order to perform the sensing of the selectively applied magnetic fields of imaging system 10, shielded Z-axis gradient field sensors 12 can be disposed at each end of surface coil position sensor 14. Sensors 12 can be sensing coils. A voltage is induced in each gradient field sensing coil 12 by the audio frequency B1 field produced by gradient field coils 9 of magnet system 6. It will be understood that the gradient field sensed by sensing coils 12 is related to the distance along the Z-axis. In particular the amplitude of the gradient field B1

is zero at magnetic isocenter 18 and gets larger moving away from magnetic isocenter 18 as shown in Fig. 2A. The amplitude drops off rapidly past the ends of magnet system 6.

The amplitudes of the voltages induced on sensing coils 12 are applied to comparator 16. The amplitude of each induced voltage depends on the distance of the corresponding sensing coil 12 from system magnetic isocenter 18 since the amplitude of the induced voltage is determined by the magnitude of the gradient B1 field. The amplitudes of the induced voltages applied to comparator 16 by sense coils 12 can be compared by comparator 16 and the relative amplitudes used to provide spatial information. Optionally, phase can be used to determine the relative positions of magnetic isocenter 18. The determinations can be made for example, by table lookups, mathematical calculations or any kind of comparison device. It is well known by those skilled in the art how to use such tables and calculations to determine the relative positions of surface coil array 24 and magnetic isocenter 18 in this manner. It will be understood that any known sensing device capable of providing an indication of the magnitude of the static [B0] magnetic field, the audio frequency gradient, the transmit RF magnetic field or the gradient time varying [B1] magnetic field can perform the functions of sensing devices 12.

In an alternate preferred embodiment, the relative positions of system magnetic isocenter 18 and surface coil array 24 can be determined using the transmit RF B1 field pulses generated by the system body coil. In practicing this alternate embodiment, it will be understood that there is a spatial dependency of the magnitude of the RF transmit B1 field along the Z-axis of system 10 which runs from the head to the foot of the imaging subject. This field is typically maximum at magnetic isocenter 18 and drops off rapidly beyond the ends of the system transmit body coil, as shown in Fig. 2B. It will also be understood that sensing devices 12 and comparator 16 can provide signals to logic unit 36 in order to control

RF switch 42 according to the B0 field in the manner previously described with respect to the B1 field.

In a variation of the above alternate embodiments, more than two field sensing coils 12 can be provided for measuring the magnetic fields of magnet system 6 and determining the relative positions within magnetic resonance imaging system 10. The use of additional sensing coils 12 helps to determine the isocenter and field drop off points beyond the ends of imaging system 10, and thus the relative positions of surface coil array 24 and the body coil.

Logic unit 36 applies control signals to switch control line 38 according to sensing signals from sensing coils 12 of position sensor 14 by way of sense line 32, as previously described. In performing these operations, logic unit 36 can determine which M surface coils 26a-n within surface coil array 24 are required for a desired scanning range during imaging of the subject. RF switch 42, which performs the coupling of surface coils 26a-n to input lines 46a-m and the decoupling of surface coils 26a-n from input lines 46a-m under the control of logic unit 36, can include a PIN diode type switch or any other type of switching device capable of performing the required operations. For example, in the case wherein N=8, RF switch 42 can include four PIN diode switches, each PIN diode switch being capable of connecting either of two surface coils 26a-n to a single input line 46a-m.

Surface coils 26a-n are typically disabled in two ways when they are not selected within magnetic resonance imaging system 10. They can be disconnected from phased array coil input lines 46a-m using series PIN diodes within RF switch 42. Additionally, the transmit PIN diode can be biased on at all times. Thus inactive surface coils 26a-n can be held in an inactive state by switching the inputs into a decoupled state using the same means used for transmit decoupling of the surface coil 26a-n.

Referring now to Fig. 3, there is shown magnetic resonance imaging system 70 of the present invention. Magnetic resonance imaging system 70 is an alternate embodiment of nuclear magnetic resonance imaging system 10. In imaging system 70, each pair of surface coils 26a-n is provided with a separate sensing coil 12a-p. The outputs of gradient B1 field sensing coils 12a-p are applied to comparator 16 by way of converters 15. During imaging of a subject using imaging system 70, comparator 16 compares the outputs of sensing coils 12a-p and determines which output has the smallest amplitude, corresponding to the location closest to the system isocenter. Alternately, RF B1 sensing coils and the largest amplitude, corresponding to the same location, can be used. The surface coils 26a-n corresponding to the sensing coils 12a-p having the smallest output amplitude are selected and enabled by RF switch 42 according to control signals on switch control line 38, as previously described.

Referring now to Fig. 4, there is shown magnetic resonance system 90 of the present invention. Magnetic resonance system 90 is an alternate embodiment of nuclear resonance system 10. In imaging system 90, field energy received by surface coils 26a-n is sensed by sensing coils 12. The outputs of sensing coils 12 are applied to comparator 16 by way of converters 15. Thus, as previously described, the correct sensing coils 26a-n can be selected using switch 42.

The present invention advantageously provides automatic selection of phased array coil elements appropriate for an anatomical region being scanned, without scan room intervention. Coil elements of the array may be automatically selected to image anatomical regions of a patient according to the locations of the coil elements relative to the isocenter of the MRI system. Further, coil elements appropriate for an anatomical region to be scanned may be selected by moving the target anatomy of the patient to the magnetic isocenter of the MRI system.

By providing automatic coil selection, the present invention eliminates the need for scan room intervention to physically reposition the surface coils or to manually switch selected groups of coils after successive scans to image the desired anatomical regions of patients. Accordingly, the present invention can decrease both examination time and the likelihood of a patient rejecting the procedure.

It should be appreciated that changes and modifications may be made to the above-described embodiments of the present invention. Therefore, the embodiments described above are to be considered in all respects as being illustrative of the present invention, and not restrictive.

WHAT IS CLAIMED IS:

1. A method of selectively enabling at least one of a plurality of receive coils of a coil array adapted for use with a magnetic resonance imaging system having a scanner and a magnetic field, the receive coils being movable with respect to the magnetic field,

characterized by the steps of:

providing at least one sensor;

sensing the magnetic field with the at least one sensor;

selecting at least one receive coil of the plurality of receive coils in accordance with the sensing of the magnetic field; and

enabling the selected at least one receive coil to form a magnetic resonance image.

2. The method of claim 1, further characterized in that the at least one sensor comprises a coil.

3. The method of claim 1, further characterized in that the at least one sensor comprises a plurality of sensors.

4. The method of claim 3, further characterized in that the magnetic field has an longitudinal axis and the plurality of sensors are disposed along the axis.

5. The method of claim 3, further characterized in that the magnetic field has differing field amplitudes at differing locations. and the plurality of sensors are disposed at differing locations to sense the differing field amplitudes.

6. The method of claim 5, further characterized in that the step of selecting comprises selecting at least one receive coil according to a comparison of the sensed differing field amplitudes.

7. The method of claim 1, further characterized in that the step of selecting comprises selecting a plurality of receive coils in accordance with the sensing.

8. The method of claim 7, further characterized by the step of determining a number of the plurality of receive coils to be selected in accordance with the sensing.

9. The method of claim 7, further characterized in that the imaging system comprises externally provided selection information.

10. The method of claim 9, further characterized by the step of determining a number of the plurality of receive coils to be selected in accordance with the externally provided selection information.

11 The method of claim 1, further characterized by the step of electrically coupling the selected at least one receive coil to the scanner having at least one scanner input.

12. The method of claim 11, further characterized in that the at lest one receive coil comprises N coils, the at least one scanner input comprises M scanner inputs, and N > M.

13. The method of claim 12, further characterized in that the number of receive coils selected is less than or equal to M.

14. The method of claim 1, further characterized in that the magnetic field comprises one or more of a gradient B1 field, an RF B1 field, and a static magnetic B0 field.

15. The method of claim 14, further characterized in that the step of sensing comprises sensing at least one of the gradient B1 field, the RF B1 field and the static magnetic B0 field.

16. The method of claim 1, further characterized in that the plurality of receive coils are arranged in pairs of receive coils and the pairs of receive coils are provided with corresponding sensors.

17. The method of claim 1, further characterized in that the at least one sensor is responsive to a selectively applied gradient B1 magnetic field.

18. The method of claim 1, further characterized in that the at least one sensor is responsive to a transmit B1 magnetic field.

19. The method of claim 3, further characterized in that the plurality of sensors are adapted to selectively sense either a gradient B1 magnetic field or a transmit B1 magnetic field.

20. The method of claim 3, further characterized in that the magnetic field has differing phases at differing locations and the plurality of sensors are disposed at differing locations to sense the differing phases.

21. A magnetic resonance imaging system comprising a plurality of receive coils movable with respect to a magnetic field for imaging anatomical regions of a subject,

characterized by:

at least one sensor having a known position with respect to the subject for sensing the magnetic field; and

a switching device for selecting at least one of the plurality of receive coils in accordance with the sensing of the magnetic field by the at least one sensor.

22. The magnetic resonance imaging system of claim 19, further characterized by an imaging device for forming an image of the subject in response to selecting at least one of the plurality of receive coils.

23. A magnetic resonance system having a magnetic field,

characterized by:

a sensor device for determining the position of a subject within the magnetic field, the sensor device comprising at least two sensors movable within the magnetic field for sensing the amplitudes of the magnetic field at differing locations therein and for determining the position of the subject within the magnetic field in accordance with the amplitudes sensed by the at least two sensors.

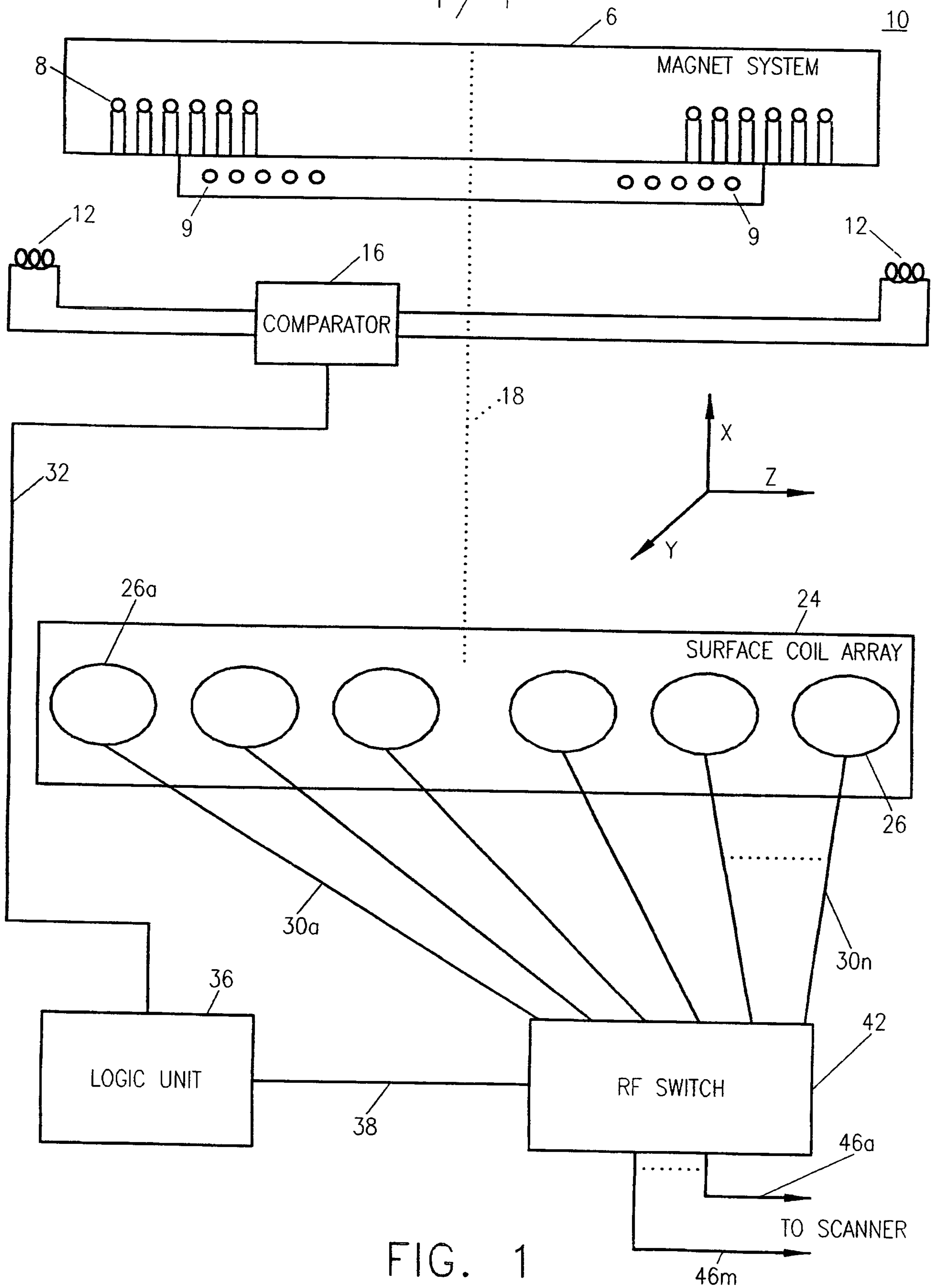

10
6
MAGNET SYSTEM
8
9
9
12
12
16
COMPARATOR
18
X
Z
Y
32
26a
24
SURFACE COIL ARRAY
26
30a
30n
36
42
LOGIC UNIT
RF SWITCH
38
46a
TO SCANNER
46m

FIG. 1

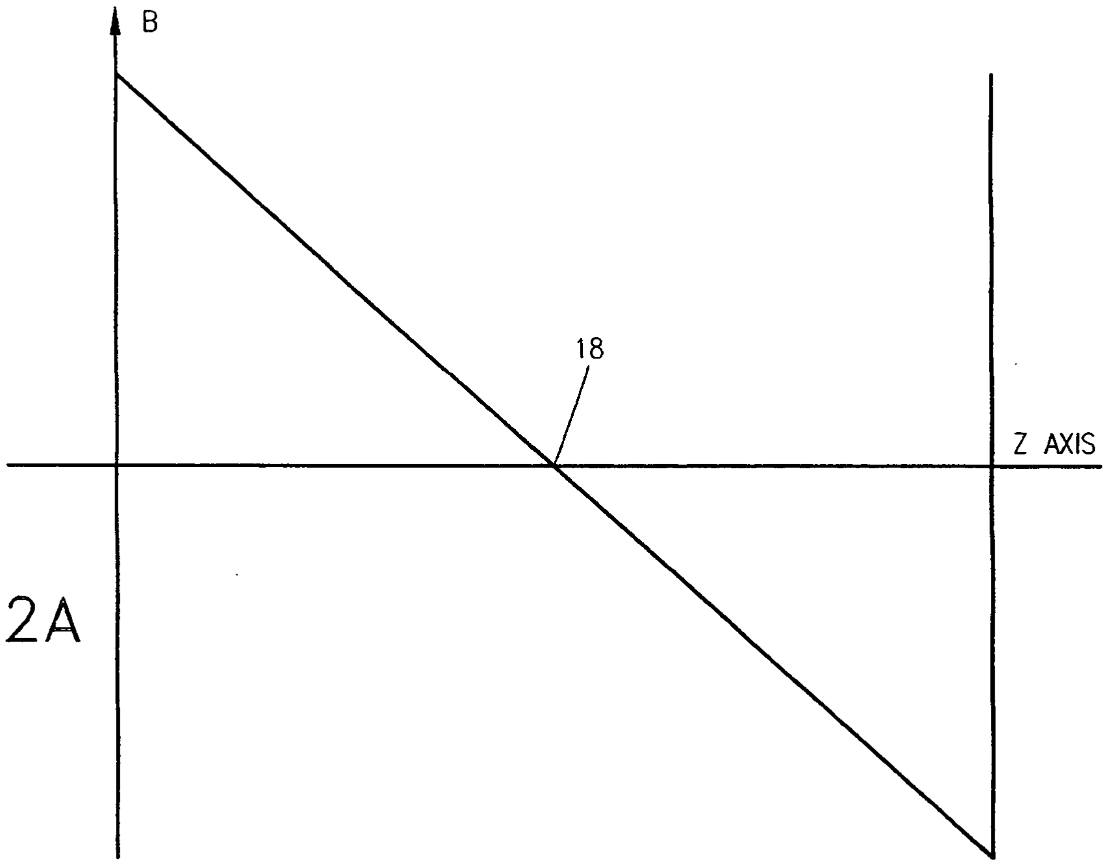


FIG. 2A

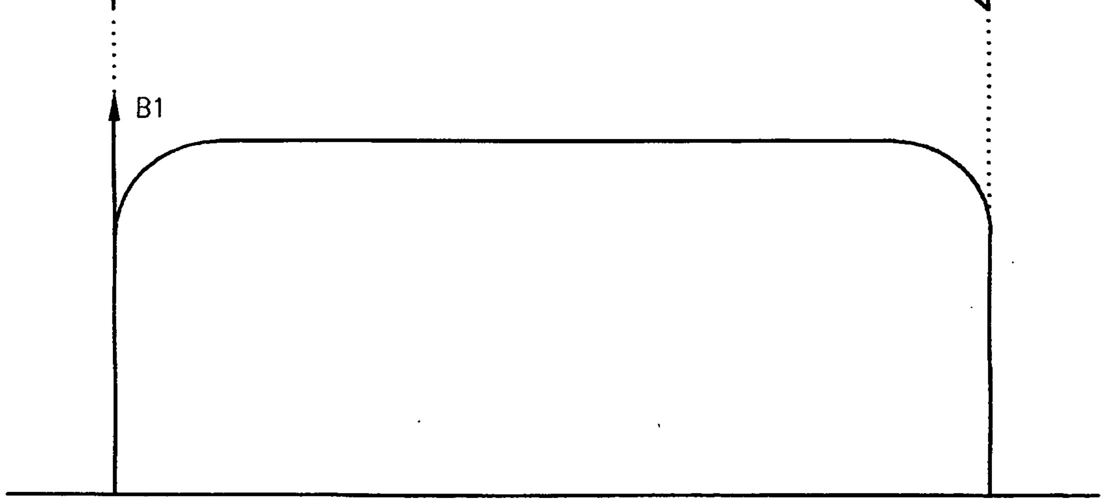
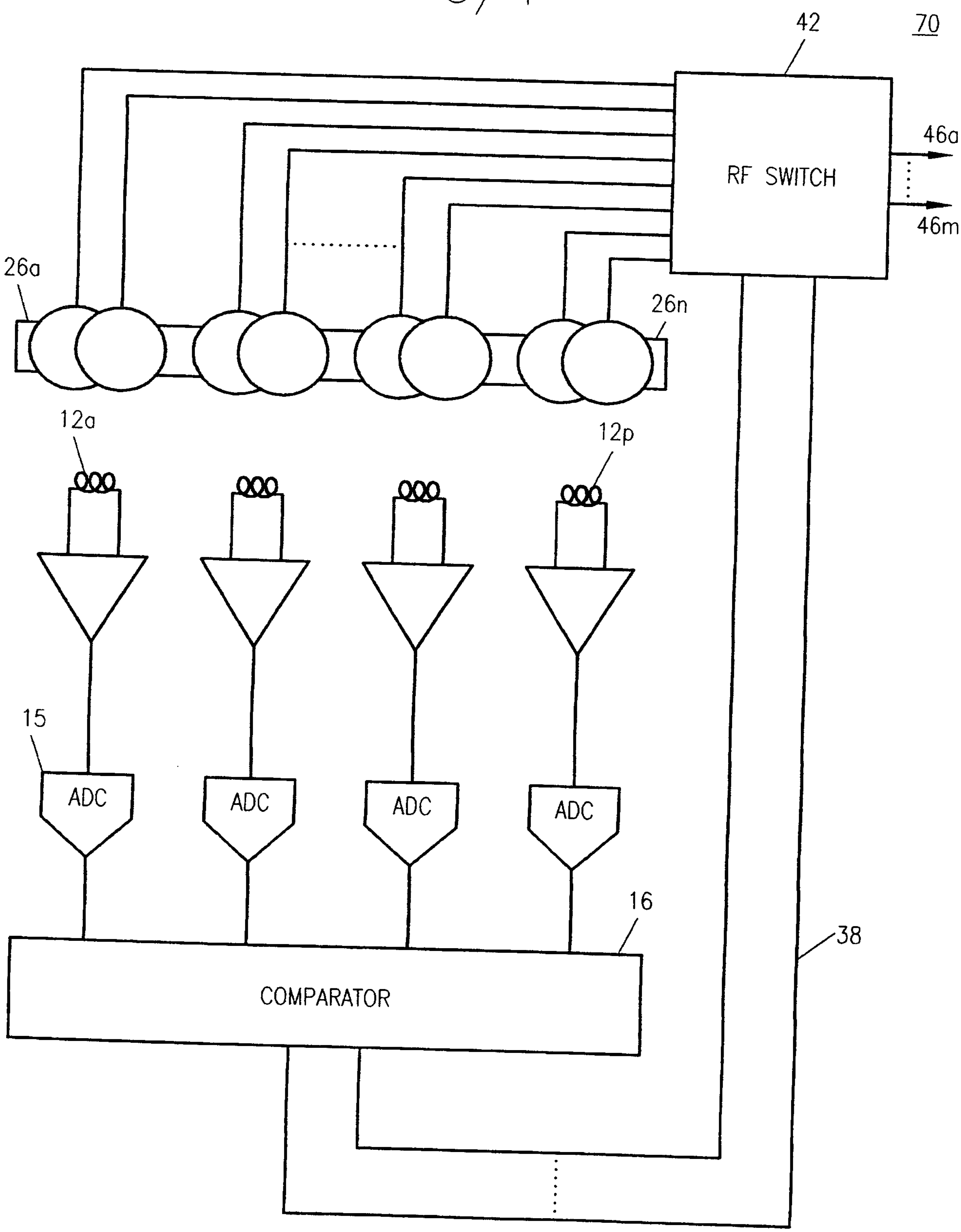


FIG. 2B



42
70
RF SWITCH
46a
46m
26a
26n
12a
12p
15
ADC
ADC
ADC
ADC
16
38
COMPARATOR

FIG. 3

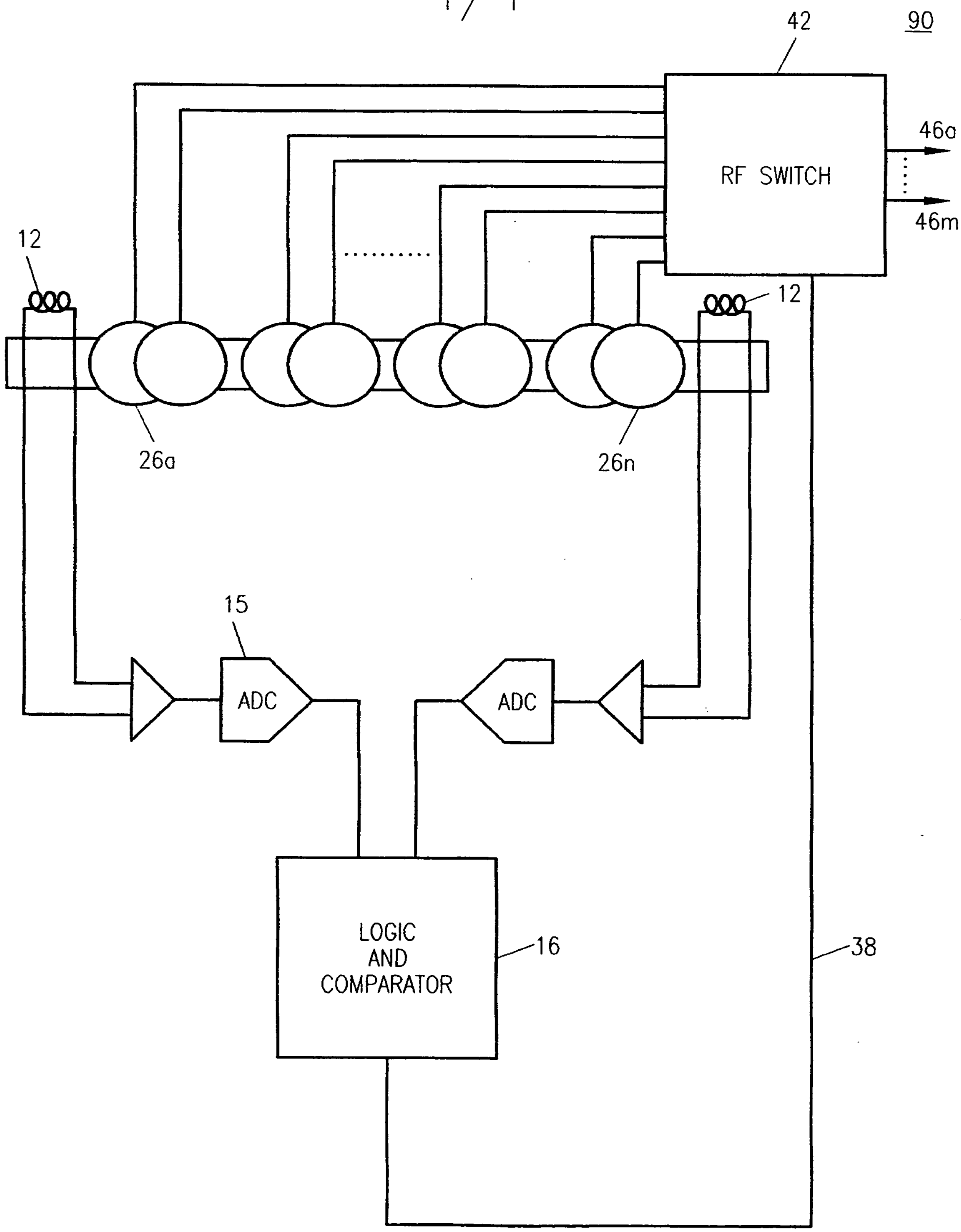

42
90
RF SWITCH
46a
46m
12
12
26a
26n
15
ADC
ADC
LOGIC
AND
COMPARATOR
16
38

FIG. 4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/07851

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01R33/28

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G01R A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 706 813 A (FILLER AARON G ET AL) 13 January 1998 (1998-01-13) column 10, line 51 - column 11, line 63; figures 2,3,5 ---	1-3, 5-11,14, 15,18, 19,21,22
X	US 5 558 091 A (ACKER DAVID E ET AL) 24 September 1996 (1996-09-24) column 1, line 6 - column 1, line 10 column 8, line 42 - column 13, line 47 column 18, line 60 - column 20, line 50 column 22, line 60 - column 22, line 67 column 23, line 16 - column 23, line 62 column 25, line 59 - column 26, line 21; figures 1,2,9 --- -/--	23

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
27 July 1999	13/08/1999

Name and mailing address of the ISA	Authorized officer
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2

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 729 129 A (ACKER DAVID E) 17 March 1998 (1998-03-17) column 8, line 61 - column 9, line 42 column 13, line 6 - column 14, line 7; figures 1,5,6	23
A	US 5 144 243 A (NAKABAYASHI KAZUTO ET AL) 1 September 1992 (1992-09-01) column 1, line 33 - column 1, line 67 column 4, line 22 - column 5, line 8 column 7, line 3 - column 8, line 2; figures 3,6,10-13	1,4,6, 11,21,22
A	US 5 551 430 A (BLAKELEY DOUGLAS M ET AL) 3 September 1996 (1996-09-03) column 3, line 17 - column 6, line 5; figures 1,2	1,7-11, 14,21,22

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
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